Description and representation of segmented renal arteries from angiograms.

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ABSTRACT

This paper presents the first prototype of a system that uses syntactic techniques to describe normal and abnormal aspects of segmented renal arteries from angiographic images. The system is one part of a full understanding system devoted to the interpretation of angiograms. Its purpose is to provide symbolic descriptions of lesions that can further contribute to an accurate diagnosis from the image. The prototype consists of a modular system that takes artery outlines as input and provides a structural description of the artery as output in the framework of a precise quantification scheme. Each module yields heuristic parameters that influence the resulting description. The system is intended to be a tool to study independently the role of these different parameters in the inter and intra observer variability.

INTRODUCTION

Digital subtraction angiography can characterize both functional and morphological features of arterial or venous networks. The images given by blood vessels are first enhanced by injection of a contrast agent and further improved by subtraction of a precontrast from a post contrast image. Angiograms are a valuable support for the physician to evaluate the severity of visible lesions and consequently to propose the best therapy. Nowadays, the lack of objective and descriptive criteria for angiographic images causes inter and intra observer variations in the description and interpretation of artery lesions [1]. There has been much effort to develop computer systems able to provide accurate quantitative data from the image so as to reduce this variability. Some of the research work in this area is aimed at the elaboration of high level 3D geometrical representations of arteries from cine-angiograms [2][3]. Such representations obviously reduce part of the subjectivity in the perception of the artery outline. However, the determination of accurate quantitive data from the 3D or 2D contours is domain-dependent and still subject to a large variability. Over the last decade, research in the domain of automatic quantification of artery lesions from 2D angiographic images has focussed on the quality of the segmentation process that provide the outlines of the arteries. The difficulties stem from the fact that the obtention of precise outlines often requires operator intervention [5][6] while an automatic segmentation process is prerequisite to the reproducibility [7][8]. Downstream the segmentation procedure, there has also been work to extract quantitative data from the contours [9].

The values that characterize pertinent qualitative features such that the lumen width, the excentricity of a lesion, the taper, the tortuosity or axial smoothness of the lumen [4] are not well known except, may be, the dregree of stenosis [9]. A good quantification scheme that could be used by physicians, may reduce the variability of evaluations. Such a scheme could be based on the identification of the pertinent parameters of the domain, the definition of metrics that can be used to measure them and the definition of the set of possible values for each parameter. Our objectives are first to define the quantification scheme and second to describe automatically the perceived arteries in this scheme. The first step of our work, which is presented here, is the development of the overall system that provides the description. The second step will be to study the sensitivity to small variations, reproducibility and precision of the description. Our long term goal is to be able to obtain a reproductible, objective and complete quantification of a lesion as well as a semantic description of the artery that can be integrated into more general decision support systems.

The present work deals with 2D renal artery angiographic images. Angiography is indicated by hypertension. In this context, our contribution is downstream the segmentation procedure. We present the first prototype of a system that extracts the structural description from the artery outline. We describe the quantification scheme and the modules that are required for the description. Each module is centered around a specific heuristic that has a significant effect on the resulting description. The main module of the system performs the syntactic analysis of the artery using a regular grammar.

THE QUANTIFICATION SCHEME.

The usual description of the normal and abnormal aspects of the artery in radiological reports (written in natural language by the radiologist) follows specific syntax rules of the form (lesion) -> (topography) (see figure 1).

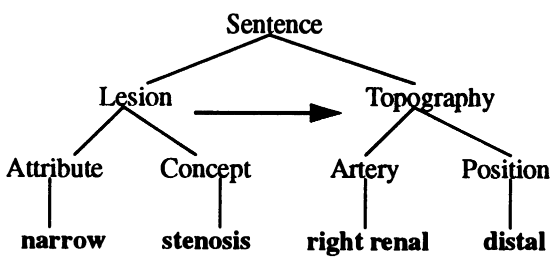


figure 1 : Syntax of a description

These reports contain two kinds of pertinent quantities :

- Quantities derived from anatomo-pathological knowledge appear in the description as linguistic labels such that *narrow stenosis*, *normal segment* or *post-stenotic dilatation*. These labels can be modeled by the set of concepts and attributes that are presented in the figure 2. A label is represented by the expression : (Attribute (Space Value)). The Attribute refers to a specific dimension of a concept (the degree of the stenosis for instance). The Space refers to the space of reference of the attribute : it can be discrete e.g. {light, narrow, very-narrow} or continue e.g. [0%, 100%]. The Value is the value of the attribute in the space. In this model, a quantity is defined as a label which space is a subset of IR, like for instance (Length-Stenosis ([0cm 30cm] 3)).
- Quantities derived from anatomical knowledge. Local topographical information (e.g. the position of a lesion) is represented in the same way as other quantities and integrated in the quantification scheme at the lesion level (figure 2). Global topographical information corresponds to the recognition and anatomical naming of the artery. This kind of information is defined by artery labeling procedures [10][11] or bifurcation labeling procedures [12]. In our work, such information is immediate since we only consider renal artery angiogram

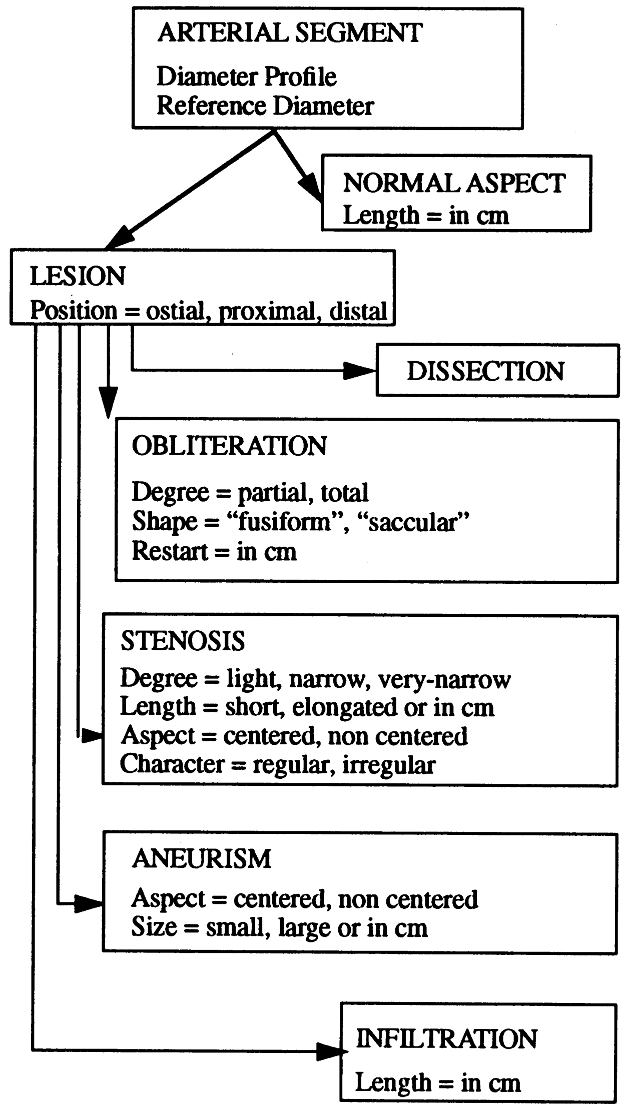


figure 2 : Hierarchical organization of concepts

In the first prototype of our system, there were restrictions on the quantification scheme. The concepts that were first considered for the *lesion* one (figure 2) were the *stenosis, aneurism* and *infiltration*. The concepts are represented by uppercase letters : **N** for normality; **S** for stenosis, characterized by a decrease in the diameter of the artery in the radio-anatomical image; **D** for aneurism, or the increase in the diameter of the artery; and **I** for infiltration, or irregularity in the boundaries of the artery. Examples of quantitative data that can be expressed in this scheme are : (Length-**N** ("in cm" x)) (Position-Lesion ("in cm" x)) (Degree-**S** ([0% 100%] x)) (Length-**S** ("in cm" x)) (Size-**D** ("in cm" x)) (Length-**I** ("in cm" x)).

The system that we constructed measures these quantities directly from the artery outline without the intervention of the operator.

DESCRIPTION OF THE SYSTEM

The steps involved in defining the structural description are represented in figure 3.

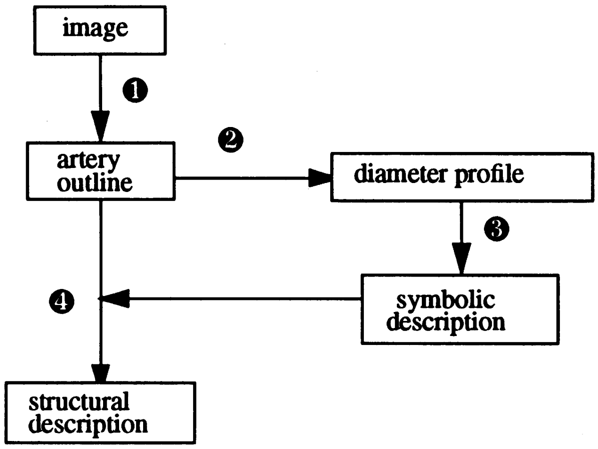


figure 3 : Functional architecture of the system

The artery outline (❶).

Image processing techniques are used to perform the segmentation. Most angiographic techniques are semi-automatic and require the operator to define a region of interest, a coarse median axe or at least some start-of-search points [13]. There has been some work to develop automatic segmentation [8], sometimes using production rules to recover the shape of the vessels from the coarse contours [7]. In the present work the outlines are computed semi automatically from scanned images using specialized software on Macintosh (figure 4).

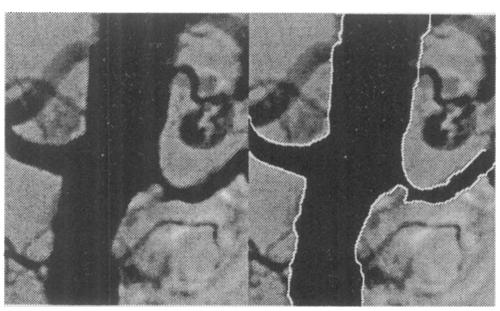


figure 4 : The artery outline.

The resulting artery outline is assumed to be correct in the subsequent steps of the system. In the future, the overall system should comprise a low-level vision module for automatic or semi-automatic segmentation of a specific region of interest in the image.

The diameter profile (❷).

The diameter function [4][6][9] is a fundamental notion since most of the quantities of the quantification scheme can be derived from the diameter of the artery. Our approach is to sample the artery to compute the diameter function (figure 6). A technique similar to the "adaptive tracking" technique [8] is used for sampling. The mean direction of the median axe (given by d=(d1+d2)/2) is computed at each step of the tracking procedure to find the next diameter (figure 5). In the first prototype of the system, the step of the sampling (represented by the **e** in figure 5) can be changed interactively. The system can be used to study the sensitivity of the description to **e**.

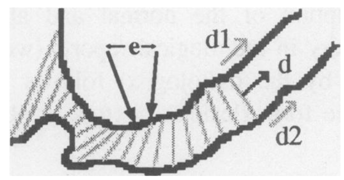


figure 5 : Sampling of the artery

The symbolic description (❸).

A symbolic description is extracted from the diameter profile (figure 6). The process is decomposed into three steps, the determination of a reference diameter, the initial classification and the syntactic analysis of the classification.

- **The determination of the reference diameter.**

The reference diameter (**dr**) is defined as the diameter of the healthy artery for the patient. **dr** can be corrected for different patients using the absolute dimension of the catheter visible in the image [9]. The taper of the artery at the bifurcation with the aorta (for renal arteries) is also considered to correct **dr**. We use a threshold **t** for proximal points of the diameter profile for this correction. In the first version of the prototype, **t** is defined as the maximum of the remaining points (for instance in figure 6, **t** = 20).

The determination of the reference diameter is crucial since it represents the "gold standard" for comparisons of the quantities that are subsequently measured. The difficulty stems from the fact that there is no single measurement for evaluating **dr**. Indeed, if an artery presents only a local stenosis, then **dr = max di** for **i** along the artery; if an artery presents only a local dilatation, then **dr = min di** for **i** along the artery. The mean, **dm**, and median are sometimes used to define **dr**. However, in order to avoid ambiguity, **dr** is usually defined by the operator [9] and thus subject to variability. We used the value "most frequent diameter", **df**, which is expected to be a valid notion for normal segments or local lesions. We then define **dr = (dm + df) / 2** restricting our domain to local lesions. This measure was validated on a set of 20 angiographic images where the reference diameter was given by a radiologist.

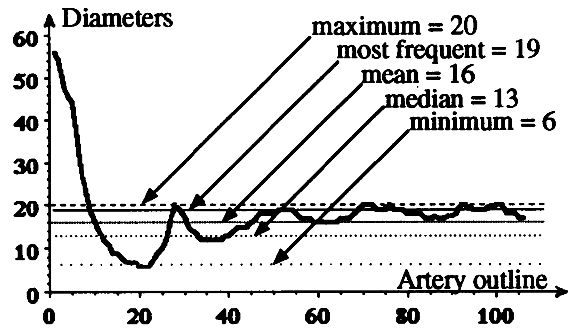


figure 6 : The diameter profile and the reference diameters

- **The initial classification**

The initial classification simply transforms the diameter profile (after the taper correction) to give a new representation (figure 7). In this representation, lowercase symbols **s**, **i**, **n** or **d** are used for each step of the sampling as follows:

s if the diameter is < 0.5**dr**
i if the diameter is ≥ 0.5**dr** and < 0.8**dr**
n if the diameter is ≥ 0.8**dr** and 1.2**dr**
d if the diameter is 1.2**dr**

The coefficients 0.5, 0.8 and 1.2 were defined by radiologists from their expert knowledge of the subject. For the example in figure 6, the result of the initial classification is shown in figure 7.

nnnnnnnnnnnniiiissssssssiiinnnn
nniiiiiiiinnnnnnnnnnnnnnnnnnnn
nnnnnnnnnnnnnnnnnnnnnnnnnn
nnnnnnnnnnnnnnnnnnnnnnn

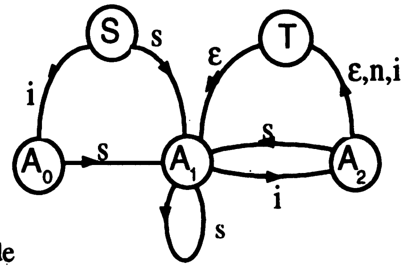
figure 7 : The initial classification

Obviously, the result of the initial classification depends on the step and on **dr**. In order to study further the sensitivity of the classification to these two parameters, they can be changed interactively by the user of the system.

- **The syntactic analysis**

The last step is syntactic analysis. It involves extracting the symbolic description from the result of the initial classification. The procedure makes use of the quantification scheme (figure 2). An analogy has been drawn with the syntax or grammar of languages. This has already been adopted for the recognition of normal and abnormal bifurcation in angiograms [12]. A convenient way of defining the possible sequences of primitives that constitute the different patterns **N**, **S**, **D** and **I** involves defining a recognition grammar, G, such that these sequences form a valid sentence of the language, L(G), generated by the grammar. This grammar can be defined by the four-tuple (nT, T, E, P) where nT is the set of non-terminals, T is the set of terminals (the patterns to be recognized), E is the starting non terminal expression (the result of the primary classification) and P is the set of production rules that define a regular string grammar. Currently, we implemente a finite state machine to recognize sentences of the grammar. For instance, the pattern **S** is recognized by the following automata :

S:=sA1 / iA0
A0 := sA1
A1:=sA1 / iA2 / ε
A2:= sA1 / ε / n / i



ε is the empty string
T is the terminal node

The resulting symbolic description of the previous example is given in figure 8:

N-S-N

figure 8 : The symbolic description

The structural description (❹).

The extraction of the structural description involves computing the quantities for each identified patterns. The attributes Length-N, Position-Lesion, Length-S and Length-I are all measured along the abscisses axis of the diameter profile. For the Position-Lesion attribute the value corresponds to the abscisse of the point where the lesion starts. By convention, the value of the attribute

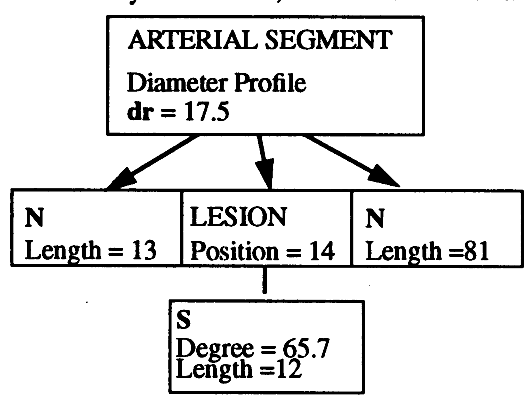


figure 9 The structural description

Size-**D** is the value of the diameter of the point which is at the middle of the identified **D** pattern. Consequently the space of reference of the attribute Size-**D** is given by **[dmin, dmax]**. The attribute Degree-S takes its values according to the classical formulation of the degree of severity of a stenosis [9]. In the approach used by Reiber and al. [9], the attribute Degree-S is given by the expression: **%-Dstenosis = (1-dmin/dr)x100%** where **dr** is indicated by the user. We use this measure in our system and the space of reference of the attribute Degree-S is [0%, 100%]. The figure 9 shows the final structural description of our example of artery.

RESULTS

This article presents a framework for high-level structural renal artery descriptions from 2D angiograms. A first prototype of the system has been implemented in the C++ language in a DecPC environment. The output of the system is a semantic description of the artery. Currently, the system works on a restricted quantification scheme. Future extensions of the scheme consist of defining the metrics that can be associated to the attributes Degree-O (O for obliteration), Shape-O, Restart-O, Aspect-S, Character-S and Aspect-D.

The system performs a sequence of treatments each of which exploits specific aspects of the knowledge of the domain. The reference diameter determination combines different possible measures and the extraction of the structural information is based on a syntactic analysis of the artery diameter profile.

The first results show how an automatic description of lesions can be obtained from the artery outlines. The reproducibility and objectivity are ensured by the absence of operator intervention in the system. However, the clinical validity of the results depends on experts agreeing on the definition of the attributes and the meaning of the corresponding quantitative values. The other parameters that intervene in the sensitivity of the structural description to small changes are the step of the sampling, the reference diameter, the coefficients of the classification and the production rules of the grammar. Each module of the system is responsible for one of these four aspects. In the first version of the prototype, all these parameters can be changed interactively so that the system also provides a formal framework for further evaluations of the sensitivity of the structural description to these parameters.

DISCUSSION AND CONCLUSION

The motivation of this work is to identify and study the subjective parameters that are responsible for the variability in the characterization and quantification of normal and abnormal aspects of renal artery from a 2D angiographic image. Our approach is to build a computerized system that performs the syntactic analysis of the artery. The resulting description and quantification are extracted automatically but are dependent on these parameters. There has already been much work with the same goal to obtain accurate quantitative data for the final diagnosis [4][6][7][8][9]. However, most of this work has focussed on the segmentation procedure of angiograms. The comparison of methods is difficult because of the lack of common databases. It appears that automated segmentation, including knowledge-based approaches, has been more widely used for vascular network labeling applications [7][8][10][12] while efforts to pure quantification have assumed semi-automatic segmentation [4][6][9].

The variability we are concerned with is not that resulting from different perceptions of the outline but that resulting from the use of the knowledge of the domain. Therefore our work is complementary to advances in the segmentation procedure and, indeed, the system should include a low-level vision module to perform the segmentation.

Syntactic techniques have also been used in the domain of computerized angiographic images [12] where the primitives are geometrical (stick like) and thus very sensitive to the segmentation process. The results were very encouraging. A correct classification between normal and abnormal carotid bifurcations is obtained for the tested patients. Our approach is different only in the sense that the primitives are already symbolic since they result from the initial classification.

Many other issues have to be considered before this prototype can be developed into an applicable system. One is to make several images cooperate in order to get a synthetized description. An another aspect is to extend the domain to a fuzzy quantification scheme [14] to represent the fuzzy meaning of quantities that are commonly used in radiological reports. Finally, storage of the structural description with the images should be possible to support efficient and contextual retrieval of images in large databases.

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